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Multi-Representation Databases with Explicitly Modelled Intra-Resolution, Inter-Resolution and Update Relations

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Abstract

This paper presents a new approach combining multi-representation databases with the generalisation and update process. It leads to a tightly integrated model, which is implemented as a part of the existing cartographic GIS *axpand*. The approach is based on the mathematical concept of relations and, in particular, on the three different types of relations: intra-resolution, inter-resolution and up-date. Intra-resolution relations allow the representation of relationships between features within one resolution. Examples are partitions, neighbourhood and topology. The inter-resolution relation represents the relationship between features of different resolutions. This originates from a generalisation or matching process. The update relation describes temporal changes of features. After a detailed theory about the introduced relation types the paper continues with a discussion of their similarities and differences with focus on implementation in a multi-representation database. Finally some exemplary results of the integrated model are presented.

1. Introduction

The lack of fully automatic real-time generalisation functionality has forced research and development of multi-representation databases (MRDB). There exists a large area of applications for MRDB in conventional map production as well as in web cartography (Jones et al., 1996; Devogele et al., 1996; Hampe et al., 2003). However, only few realisations do exist. The aim of this paper is the presentation of an MRDB implementation in a cartographic map production system. Research and development focuses thereby on explicitly modelled relationships (Neun et al., 2004; Neun and Steiniger, 2005). These support the generalisation process in two ways: First, by aiding in the analysis of data of one resolution and thus supporting the process of generalisation, and second, by maintaining incremental updates.

The relationships are divided into three different types: intra-resolution, inter-resolution and update relationships. The intra-resolution ones describe the relations between features in one resolution (level of detail, LOD). Examples are partitions, neighbourhood and topology, semantic, structure and patterns (Duchêne, 2004; Steiniger and Weibel, 2005). The inter-resolution relationships connect features between different resolutions that may be created during a generalisation process or with help of matching operations. The update relationships describe temporal changes of features that may be derived from an updating process or from matching of datasets with different time states. For each of these types of relationships we

present existing approaches for their creation and analyse their dependencies. *Intra-resolution relations* support the automated generalisation process. The result of this process is stored in different resolutions, connected by an *inter-resolution relation*. These in turn are required for automated incremental updating. The *update relation* between different temporal states enable spatio-temporal analyses.

The main result of our work is the integration of the three types of relationships in one common model within an MRDB. The similarities and differences between intra-resolution, inter-resolution and update relations are examined. An approach for explicit representation of these relationships is proposed. The result is an enriched MRDB. The advantages of this enriched MRDB are the support of updating and generalisation process, improved possibilities of data analysis over resolution and time, as well as the consistent management of geographic and cartographic data. The results can be used for exchange with generalisation services as well.

2. Theory and definitions of intra-resolution, inter-resolution and update relations

Relations are a concept widely used in a variety of fields. They are all based on the mathematical concept of *relation* in which a relation is defined as a set of tuples with a fixed length, each tuple being built from given sets. Formally a relation R is a subset of the Cartesian product of a couple of sets A_1, \dots, A_n , thus $R \subseteq A_1 \times \dots \times A_n$. The number n is called the *order* of the relation. In many cases only relations of cardinality 2 are considered, expressed by “ a is related to b ”. In a broader sense, relations of any order n with $n \geq 1$ can be considered and the relation is called *n-ary* relation. The usual case of $n = 2$ is called a *binary* relation, whereas the cases $n = 1$ and $n = 3$ are called *unary* and *ternary* relations respectively. Unary relations are a special case, in that a relation is simply a subset of the given set A_1 .

The types of relations which are important for analysis, generalisation, handling and updating of geodata, namely intra-resolution relations, inter-resolution relations and update relations are introduced in the following sections. Subsequently, combinations of these types will be examined and the possibilities of describing *relations of relations* will be discussed.

2.1 Intra-resolution relations

Intra-resolution relations characterises map features of one specific resolution or level of detail (LOD) on a defined time stamp. Examples are parthood relations, neighbourhood relations, structural relations or patterns, semantic relations and hierarchical relations. The order of the intra-resolution relations can be between 1 ... n depending on the number of features, which are characterised through the relation. A special case is the intra-resolution relation of order one, which means one feature can have a intra-resolution relation. An example is the modelling of partitions with intra-resolution relations, whereby one single feature creates a partition. Another explicit intra-resolution relation of a semantic nature, modelled practically in every GIS, is the assignment of a feature to a specific class, for example *Mainstreet* to the class road.

Very common is the modelling of binary relations applied to groups of features. For example a building alignment is modelled as a pseudo object or as a meso object (Ruas, 2000; Ruas and Holzapfel, 2003; Li et al., 2004). The relations between the individual building features and the alignment of a meso object are binary part-of relations. Our definitions deviates from

this explicit introduction of groups or pseudo objects and reduces the model to individual features and their relations only.

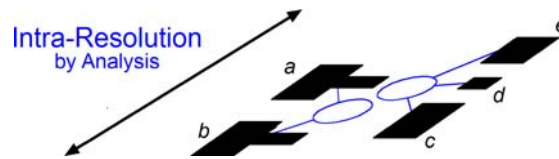


Figure 1: Intra-resolution relations on the example of building alignments: The intra-resolution relation has two elements, one connecting the buildings a and b , and the other connecting the buildings c , d and e .

Figure 1 shows a schematic view of an intra-resolution relation. Two building alignments are modelled as a relation, consisting of two elements, of which one is the tuple (a, b) and the other the tuple (c, d, e) .

Intra-resolution relations can be differentiated according to the computation complexity and the frequency of their usage. The range reaches from less complex and single usage, such as feature attribute comparison, to complex and repeated usage, such as alignments. Depending on these different cases, the relations are calculated on-the-fly and repeatedly or calculated once and stored persistently. To allow a homogenous access to intra-resolution relations in all cases the same data structure is used (see section 4). Advantages become obvious if intra-resolution relations are interpreted as sets of features with certain characteristics. The application of a common structure allows for the usage of set operations like combinations and intersections of related features, which lead to new intra-resolution relations. Furthermore, a common structure allows for the construction of functions and methods that receive a relation element as a parameter or give a relation element as a result of a calculation. Even standardisation for the use in web services is conceivable (Neun et al., 2006).

The amount and combination of possible intra-resolution relations is nearly endless and therefore a decision must be made as to which intra-resolution relation to calculate. This decision depends on the application. Of even more importance is the decision of whether to store the relation persistently or to calculate it on-the-fly. This decision must be made for each relation separately. We recommend the first for complex and frequently used relations, the latter for simple relations and relations that are seldom used. In the following section, intra-resolution relations will be presented with a focus on map generalisation of topographic maps.

Partonomic relations (partitions, global neighbourhood)

Partitions subdivide the map space in such a way that generalisation tasks can process them independently. The aim is to identify areas in which to restrict the influence of generalisation operators. The simplest case is a grid-based subdivision of the map space using a buffer area around each generalisation zone (Figure 2, left). The features inside the buffer area may influence the generalisation of features inside the grid cells, but are not modifiable themselves. Exceptions are applied to area or line features in the case where the main part is situated inside the generalisation zone. The boundary problem can be handled with this technique.

Besides these regular subdivisions of map space, contextual subdivisions are possible as well. An example is the trans-hydro-graph proposed by Timpf (1998) that describes a graph structure derived from transportation and hydrology networks. The trans-hydro-graph can be used to subdivide the task of building generalisation since buildings must stay inside the faces of the trans-hydro-graph.

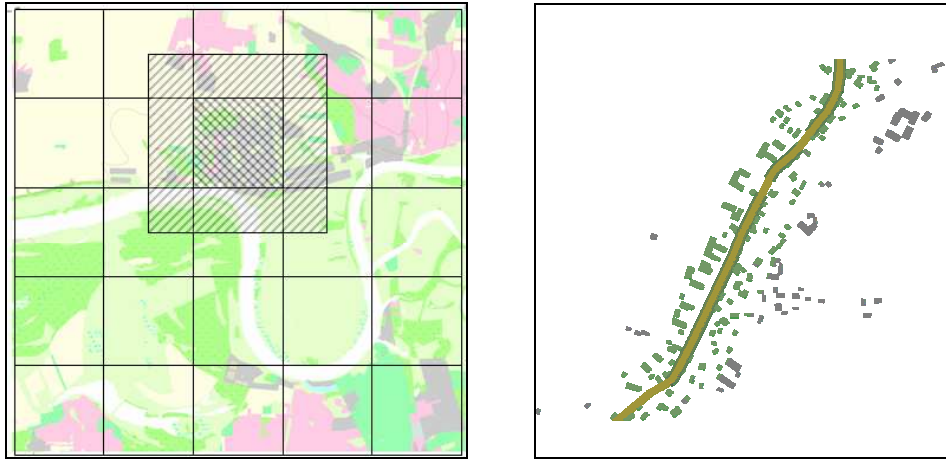


Figure 2: Examples for intra-resolution relations - buffer area around a generalisation zone (left) and line buffering (right).

Explicit storage of partitions allows for the definition of generalisation zones that describe regions, in which the same parameter values of generalisation operators have to be applied. The generalisation zones are dependent on the object classes and the applied operators.

Neighbourhood relations (distance based, topological, graph based)

In contrast to space partitioning approaches, individual neighbourhoods can be modelled as a relation in a way that each feature holds information about its local surrounding. A simple approach is the distance-based storage of features using point or line buffering (Figure 2, right). During position or shape change only the related features have to be considered. The linkage may work in both directions, which additionally informs the surrounding features if position or shape has changed.

Another way of modelling neighbourhood relations is the application of graph structures. Examples are topological data structures, transport and neighbourhood graphs, triangulations or surface networks. Here more than pure distance information is considered. Topological structures especially support the modelling of spatial relations like *connectivity*, *overlap*, *inside* etc. (Egenhofer and Franzosa, 1991; Egenhofer and Herring, 1991) Other neighbourhood relations that can be derived from graph structures are *orders of neighbourhood*, *relative orientation* or *relative size*.

Semantic relations

Semantic relations define the classification of features. In current GIS or map production systems these semantic relations are explicitly available through the data model and the layer structure. In contrast to other intra-resolution relations, they must be defined by the user and cannot be calculated from the data in general. Semantic relations are a prominent example for an unary relation, each relation describing a subset of all features that belong to a certain feature class.

Semantic relations also determine the selection and orchestration of generalisation operators, either interactively through the cartographer or through the definition of different cartographic constraints for an automated process control. The selected generalisation operators must correspond with the map feature class. For instance the *building simplification operator* can only be applied to features of the class building, and features belonging to a railway network will be generalised with different operators or parameters than features belonging to a river network.

Finally semantic relations have an influence on other intra-resolution relations: rivers, for example, must not cross one another, and terrain influences the generalisation of rivers and roads. Therefore intra-resolution relations must be defined with respect to the specific feature classes.

Patterns or structural relations

The human eye reacts quite sensitively to patterns, repetition, density differences, parallelism, orientations or global trends, which means they have to be modelled and made available during the generalisation process. Most prominent relations are alignments, especially for buildings, which have been investigated quite extensively (Li et al., 2004; Ruas and Holzapfel, 2003; Christophe and Ruas, 2002). Another example of structural relations can be found within river networks (Figure 3). Here they allow the distinction between meander, canal like, tree structures or the tectonic based parallel orientation.

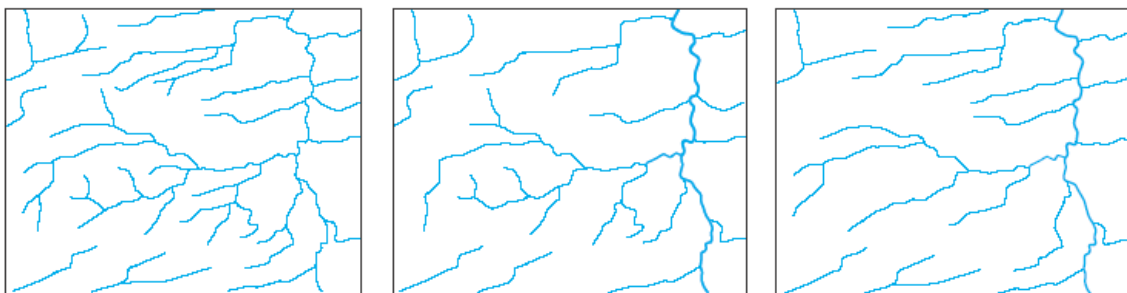


Figure 3: The detail selection of a river network (original, left) without consideration of structural relations (middle) and with explicit focus on dominant orientation (right) (pictures taken from SGK, 2002).

Further examples can be found for other feature classes such as strings of islands, street patterns (Heinzle et al., 2005), vegetation, terrain or settlement patterns.

2.2 Inter-resolution relation

The inter-resolution relation links features that represent the same real-world phenomenon in different map resolutions or levels of detail (LOD). Traditionally, linkage is created by storing a unique identification value (ID) from the corresponding features of the connected resolutions. In our approach, the inter-resolution relation is made explicit through the creation of instances of the inter-resolution relation class, whereby additionally relevant meta information about the production process can be stored (see section 3). Examples of such information are applied generalisation operators together with their parameters that produced the derived features in the case of generation by generalisation, and the matching operator in the case of generating by matching process.

The inter-resolution relations are the crucial characteristic of multi-representation databases. They support, for instance, update propagation, quality and consistency checks, multi-resolution analysis functions as well as zoom functionalities for web mapping and mobile applications (adaptive zooming). If the features of lower resolution were derived by cartographic generalisation, the inter-resolution relations may store information about the applied operators and parameters. If existing datasets from different sources were integrated the links have to be created by means of automatic matching techniques. Thereby additional information about the matching probability can be stored.

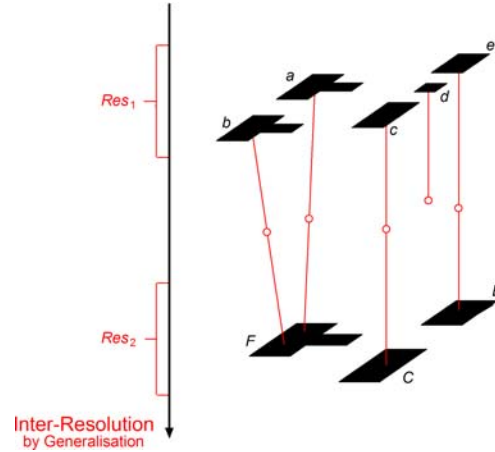


Figure 4: Schematic view on the inter-resolution relation.

Figure 4 shows a schematic view of the inter-resolution relation: The buildings a and b are aggregated into building F ; buildings c and e are generalised into C and E , while building d was omitted during the generalisation. Therefore, the relation consists of five elements, consisting of four 2-tuples (a, F) , (b, F) , (c, C) , (e, E) and one 1-tuple (d) . For discussion of cardinality see for example (Bobzien et al., 2005).

2.3 Update relation

The update relation links features representing the same real world phenomenon in different time states. It supports versioning and temporal analysis. In contrast to the inter-resolution relation the update relation resides in one resolution. The update relation might be derived from an incremental updating process. The term incremental updating (Kilpeläinen and Sarjakoski, 1995; Haunert and Sester, 2005) describes the propagation of updates within a base data set to another data set, whereby the generalisation deals primarily with the features that have changed over time (Harrie and Hellström, 1999). Additionally, neighbouring features (characterised through intra-resolution relations) have to be considered as well, since they influence the generalisation process. These neighbouring features may be identified with help of intra-resolution relations (see section 2.1).

There exist three different update operations: *insert*, *remove* and *change*. In the first two cases unary update relations, consisting of the set of inserted or removed features, are created respectively. The third case is described by a binary or n -ary relation of changed features. These may be divided into geometric and semantic changes (see section 4).

Update operations may initialise an incremental generalisation (Haunert et al., 2006). The creation of an update relation may have an effect on inter-resolution and intra-resolution relations. These relations have to be checked and possibly renewed. The interactions between intra-resolution, inter-resolution and update relation are described more in detail in the next section.

A further big challenge in cartographic generalisation, especially for incremental generalisation is the preservation of manual edits. Manual corrections will always be necessary because a fully automated generalisation solution that works in every case does not exist and will not exist in the near future (Schuurman, 1999). The process of manual correction should be kept as accurate as possible, because repetition is time consuming and therefore expensive. A cost-

efficient solution can be offered by a system that only re-generalises in required cases as a result of change in the source data. Intra-resolution and inter-resolution relations allow the identification of these tasks.

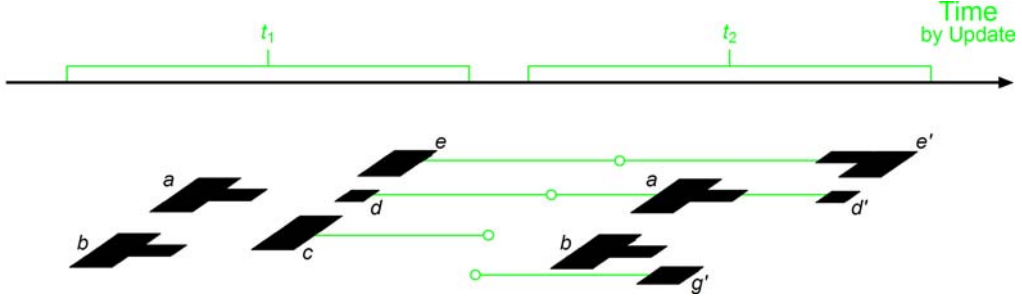


Figure 5: Schematic view of an update relation.

Figure 5 shows a schematic view of the update relation: t_1 and t_2 denote two different time states. Features a and b remain unchanged. Feature e undergoes a geometric change into feature e' , while feature d undergoes a semantic change into feature d' . Feature c is deleted, while feature g' is inserted. Further examples could include aggregation and splitting of features (see section 3), thus the update relation must provide an $m:n$ cardinality.

2.4 Combination of Intra-resolution, Inter-resolution and Update Relations

Features can be characterised through one or more instances of the above introduced relation types. Figure 6 shows a combined example of intra-resolution (blue), inter-resolution (red) and update relations (green). Therefore the same situation is presented four times, at two different time stamps (t_1 , t_2) and in two different resolutions (Res_1 , Res_2). The initial state consists of five buildings aligned into two rows shown at the upper left. The two alignments are modelled by intra-resolution relations (blue). The situation after generalisation is shown at the lower left of the figure. The buildings are typified and enlarged and the derived buildings are connected to the corresponding ungeneralised buildings by the inter-resolution relation (red).

The situation at a second time stamp is visualised in the upper right of the figure. The three possible update operations *delete*, *insert* or *change* are applied. The corresponding update relations are shown in green. The update that was propagated to the second resolution through an incremental updating is depicted in the lower right of the figure. Therefore, either the updated situation of Res_1 has to be generalised completely new, or only features that were updated will be generalised (Cooper, 2003; Jahard et al., 2003). The second case implies that for the features that were not updated the corresponding generalised features of Res_2 at t_1 need not to be updated to t_2 . However, if the surrounding features have changed, this may influence the generalised feature, although the feature itself was not updated. Thus the intra-resolution relations (describing the surroundings) have to be considered as well.

The example shows the interference of the three types of relations, which are all needed for the process of automated incremental updating.

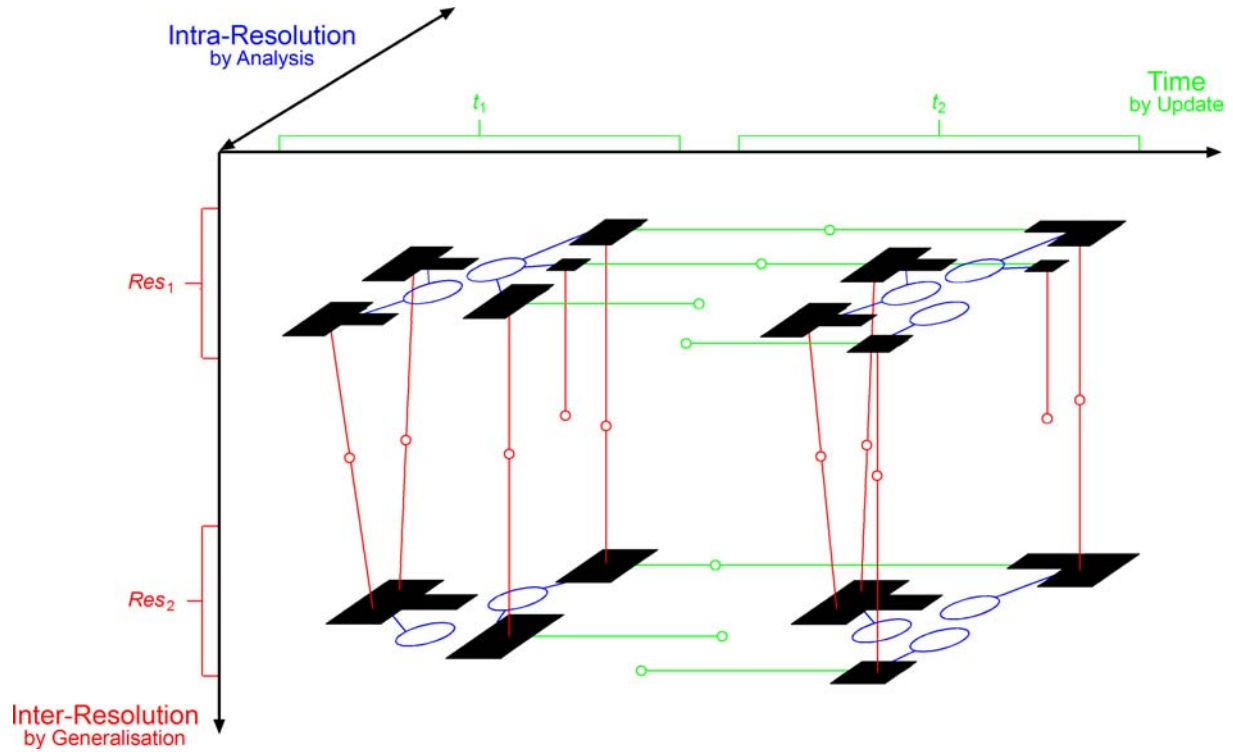


Figure 6: Combination of intra-resolution relation (red), inter-resolution relation (blue) and update relation (green).

2.5 Relations combining relations

An interesting question refers to the interrelationship between relations of different types. First the interrelationship between intra-resolution and inter-resolution relations will be discussed, second, the relationship between intra-resolution and update relations.

Intra-resolution relations characterise important context information within one resolution. If the intra-resolution relations are modelled within the origin and target dataset, they can be used to measure the quality of the generalisation process. Preservation of, grade of change and loss of intra-resolution relations lead to criteria for quality measurement. There are two possibilities for making this happen.

The first possibility considers the fact that several generalisation operators consider intra-resolution relations during execution. This implies that the resulting inter-resolution relations contain the information of the intra-resolution relations. Figure 7 (a) depicts a situation of five buildings that form an alignment in the origin dataset and are generalised into three buildings in the target data set. The information about the alignment is stored implicitly within the inter-resolution relation, which, in turn, was created by the generalisation operator that took the intra-resolution relation into account.

The second possibility is intended for those cases in which a generalisation operator acts independently from intra-resolution relations. The intra-resolution relations of the target dataset have to be built up after the process of generalisation. An explicit modelling of the inter-resolution relation between the two intra-resolution relations of each dataset, origin and target, can now take place. This relation may be used for an subsequent quality analysis of the performed generalisation operator. Figure 7 (b) depicts the situation of an explicit modelling

of the two building alignments in both resolutions. The inter-resolution relation connects the buildings of both resolutions and, additionally, the alignments are connected by an inter-resolution relation.

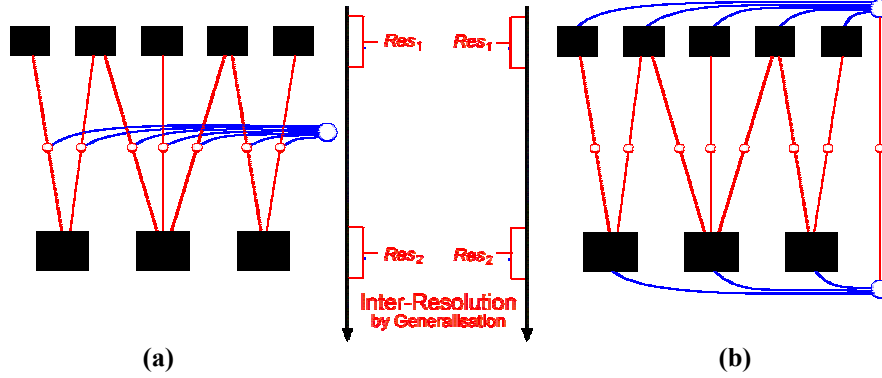


Figure 7: Combination of intra-resolution relations and inter-resolution relation. Left: The Inter-resolution relation elements are connected by an intra-resolution relation. Right: The building alignments (intra-resolution relations, blue) in different resolutions are connected with an inter-resolution relation (red).

Updates may change the context of a situation and thus affect intra-resolution relations. This may lead to deletion, change or creation of new intra-resolution relation elements after an update. To react to these changes—especially in the context of automated incremental update—it is possible to explicitly model an update relation between intra-resolution relations. Depending on the change of the intra-resolution relation, a specific generalisation update strategy may be selected. Different strategies for incremental update are discussed in (Bobzien et al., 2005). Either information gathered in a prior generalisation process may be reused, or the generalisation has to be re-calculated.

3. Similarities and Differences

In this section we discuss similarities and differences of intra-resolution, inter-resolution and update relations. Common to all three relations is the concept of data enrichment in a standardised way, through a common class *Relation*. The specification of the class *Relation* enables the explicit storage of meta-information, relevant for generalisation. The main differences refers to the arity of the relations and to the fact that intra-resolution relations describe states of features whereas inter-resolution and update relations describe the change of features.

3.1 Data Enrichment

All three relation types intend to enrich feature models by supplementary characterisation of interrelationships over space, semantics, resolution and time. The relations characterise features and describe their association by meta information, supporting the automated generalisation process. In detail, the meta information relevant for generalisation will improve the quality, efficiency and the grade of automation of the generalisation process.

Data enrichment comprises two aspects: the first one is the analysis of implicit relations and its explicit modelling. Examples are the modelling of neighbourhood relations via topology, the matching of two datasets (e.g. Sester et al., 1989) and the modelling of context informa-

tion” (Mustière and Moulin, 2002). The second aspect is the enrichment of these relations with information that is not contained in the datasets, like process information. Intra-resolution relations describe states of features whereas inter-resolution and update relations describe changes of features. Therefore the process information is only important for the latter cases.

3.2 Detailed Specification of Relations

All three relation types can be specified more detailed. Specialisations of intra-resolution relations are for example alignment relation, partitioning relation etc. (see section 2.1). The inter-resolution relation may be divided into matching relation and generalisation relation. A matching relation is built by a matching algorithm or by manual matching. The relation can hold additional information e.g. probability values. The generalisation relation is built by a generalisation operator. Additional information can be stored, such as parameters and involved features. The update relation can be distinguished by the type of operation into the insertion relation, deletion relation and change relation. The change relation can be enriched with information of the kind of changes, like geometric or attributive changes. All kinds of update relations contain a time stamp and additional information about the update process.

3.3 Arity of Relations

All relations can be modelled as n -ary relations. This modelling is suitable for intra-resolution relations since the number of related features can vary. For instance a specific partition as an element of the partition relation can contain an arbitrary number of features.

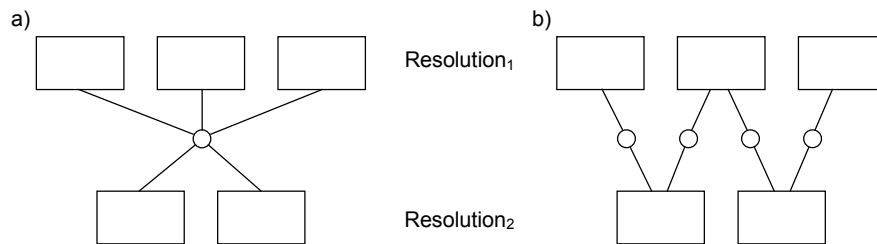


Figure 8: Two different modellings of an inter-resolution relation: modelling with an n -ary relation (left) and with a binary relation (right).

For the inter-resolution relation and the update relation the modelling as an n -ary relation is possible as well. However, here binary relations are more suitable since they imply more information than an n -ary relation. If an n -ary modelling is chosen it is uncertain which feature emerged from which other feature. Two examples of Figure 8 and Figure 9 confirm this statement for inter-resolution relation and update relation respectively.

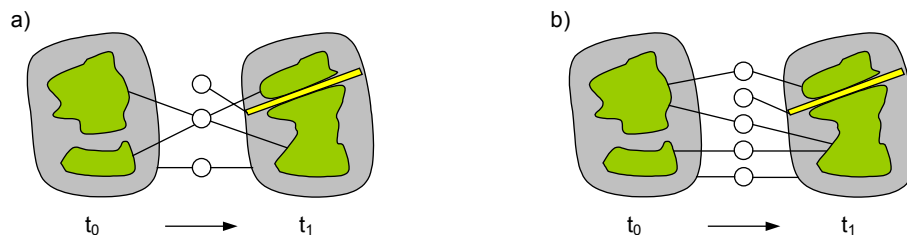


Figure 9: Two different modellings of an update relation: modelling with an n -ary relation (left) and with a binary relation (right).

In Figure 8 (a) the typification of three buildings into two buildings is modelled by an n -ary relation. If the leftmost or the rightmost building of resolution 1 receives a minor update both buildings of resolution 2 have to be updated. In contrast the binary modelling in Figure 8 (b) enables a direct detection of the building that has to be updated.

Binary relations are also more suitable for the modelling of the update relation as shown in Figure 9. The original dataset of time stamp t_0 consists of two forest areas. At timestamp t_1 a road was added and the forest area got bigger. In Figure 9 (a) all four forest areas are related with one update relation by an n -ary relation. The binary relation in Figure 9 (b) is more specialised which has advantages for the calculation of incremental generalisation. The figure shows also an example of an unary update relation characterising the inserted road feature.

3.4 Object-oriented modelling of relations

In this subsection an object-oriented modelling of the relations is presented. The standardisation of the relations enables applying operations on any relation without distinction between the specific types. A common operator is e.g. to get all features that are characterised by the given relation element. Additionally the standardisation allows the exchange of relations in a homogenous way e.g. via (web)services.

The object-oriented model is depicted in Figure 10. Each relation is represented by one of the following classes: **IntraResolutionRelation**, **InterResolutionRelation** and **UpdateRelation**. Depending on the multiplicities these relations can be differentiated as shown in UML-Diagram. The diagram is reduced to the main classes and main attributes.

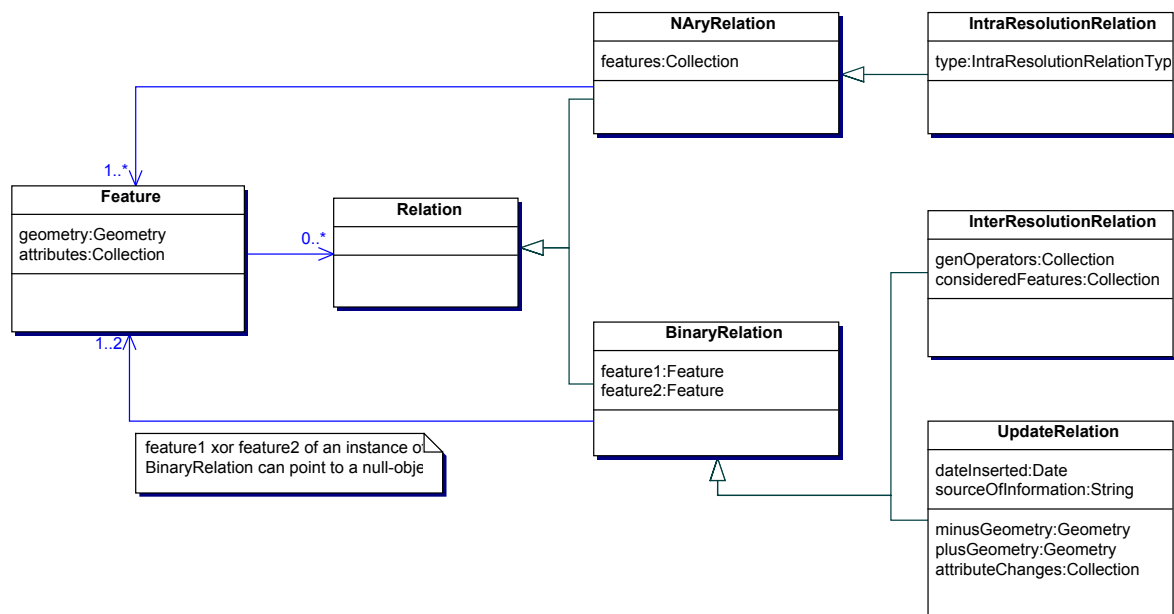


Figure 10: UML-Diagram of the implementation of relations, reduced to the main classes and attributes. An open arrow represents a directed association, with given multiplicity. A closed arrow represents a specialisation.

Each feature may have none, **one** or many association with a the class **Relation**. The relation can be specialised into **NAryRelation** and **BinaryRelation**. The difference between these both subclasses is the multiplicity of the association to the class **Feature**.

BinaryRelation is associated with one or two features. It can be specialised in the **InterResolutionRelation** and the **UpdateRelation**. The **InterResolutionRelation** stores the generalisation operator as well as all features that influences the generalisation. The **UpdateRelation** holds the information about the date of update, source of the information, differences of the geometry and modifications of the attributes.

An **NaryRelation** is associated to one or many features. The class **NaryRelation** has one subclass **IntraResolutionRelation**. The main attribute of the **IntraResolutionRelation** is the type of the relation. This attribute describes the kind of the intra-resolution relation, e.g. alignment, partitioning or feature class membership.

4. Prototype and Results

The developed approach is implemented as a part of the existing cartographic GIS *axpand* (<http://www.axpand.com>). Currently it is in the prototype status. The implementation is object-oriented under the programming language Java. For the geometrical calculations and modelling the Java Topology Suite (JTS, <http://www.jump-project.org/project.php?PID=JTS-&SID=OVER>) is used. The visualisation in this section are made with help of the Jump Unified Mapping Platform (JUMP, <http://www.jump-project.org/project.php?PID=JTS&SID=-OVER>). The data used for the following examples are taken from the Vector25 dataset of swisstopo (<http://www.swisstopo.ch/de/products/digital/landscape/vec25>) and show a part of the region near the Zurich Lake, consisting of buildings and roads.

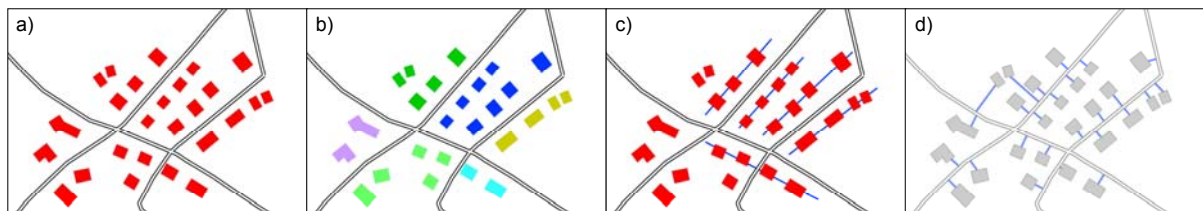


Figure 11: Intra-Resolution Relations: (a) original situation (b) partitioning by trans-hydro-graph (c) building alignments (d) neighbourhood relation between buildings and nearest road.

The original situation is depicted in Figure 11 (a). Screenshots (b)–(d) show three different intra-resolution relations that are described in section 2.1 in detail. They are derived automatically from the original dataset. The partitioning of the buildings are calculated with help of the trans-hydro-graph (b). Building alignments are detected by consideration of several constraints such as size, shape, orientation and distances between buildings and towards roads (c) (Burghardt and Steiniger, 2005). The neighbourhood between buildings and roads is computed by search of the nearest road to each building (d). The relations are modelled by the class **IntraResolutionRelation** as described in section 3, Figure 10. Partitioning and alignments are n -ary relations while the neighbourhood relation is modelled as a binary one. All three shown intra-resolution relations are used for the generalisation process as shown beneath.

The left part of Figure 12 shows an example for the inter-resolution relation. (a) shows the original situation (the same as in Figure 11 a) while (b) shows a generalised situation, derived automatically. The highlighted buildings in (a) are typified into the highlighted building in (b). The text to the right of this example is the alpha-numerical output of the two highlighted elements of the inter-resolution relation. The generalisation of all features took place with

help of the horizontal relations, namely partitioning and alignments for typification, and neighbourhood for displacement. The intra-resolution relation is modelled by the class **InterResolutionRelation** as described in section 3, Figure 10. Information about the performed generalisation process is stored within. It is a binary relation as visualised in Figure 4. The inter-resolution relation is the core of a MRDB. It is used for automatic incremental updating as shown beneath.

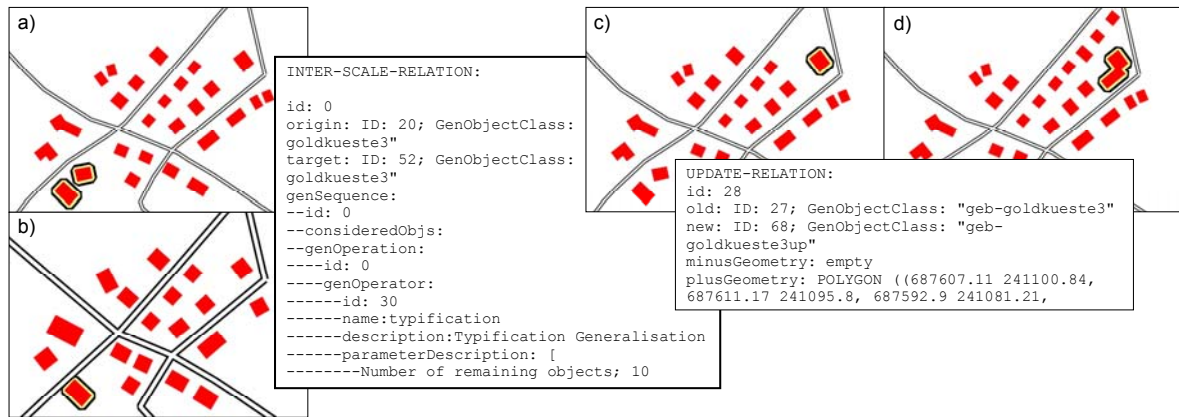


Figure 12: Inter-resolution relation (left) and update relation (right).

An example for the update relation is given in Figure 12 (c) and (d). To the right several updates took place: One building is deleted (upper middle), three buildings were inserted (upper right) and the geometry of the highlighted building has changed. The alpha-numerical output below describes the highlighted element of the update relation. In the ungeneralised dataset the update can be performed interactively by deleting, inserting or updating features. Alternatively this process can be carried out by utilizing an update dataset. In the generalised dataset the update relation is created only by automatic incremental updates as shown in Figure 13 and discussed below. The update relation is modelled by the class **updateRelation**. In Figure 5 this binary relation is depicted. The update relation realises a multi representation in the time dimension, and thus gives a different view on MRDB. The explicit modelling of the update relation is necessary for the automatic incremental updating as well as for history management, versioning and spatio-temporal analysis.

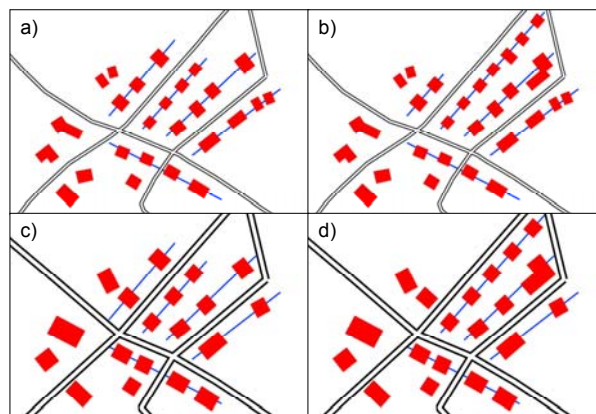


Figure 13: Interference of intra-resolution, inter-resolution and update relation. Situations: (a) original, (b) updated, (c) generalised original, (d) updated and generalised. Compare Figure 11 and Figure 12. The order of the screenshots is analogue to the order in Figure 6.

Analogue to Figure 6 in section 2.4, Figure 13 shows an example of an automated incremental updating. In all four screenshots the horizontal relation of alignments is shown. (a)

depicts the original situation, (b) the updated situation, (c) the generalised situation and (d) the result of the incremental updating process. In section 2.5 the preservation of intra-resolution relations has been discussed. In the example intra-resolution relation alignment has to be preserved during generalisation. During update the intra-resolution relations may change as shown in the example in the two upper alignments, one is shortened, the other elongated. The change of the intra-resolution relation during update influences directly the incremental update. Quite often the generalisation of an updated feature is identical to the generalisation of the original (un-updated) feature. In that case no update occurs in the generalised dataset and therefore no update relation in the generalised dataset is modelled.

5. Conclusion

This paper presents a framework for data enrichment through common modelling of relations in a multi-representation database. The relations are defined as further characterisations of features and their changes over resolution and time with focus on cartographic generalisation.

Intra-resolution relations deliver input information for generalisation operators in a standardised way to improve the quality of the generalisation results and increase the calculation efficiency. They support the modelling of groups of features, similar to the concept of meso or pseudo objects. Inter-resolution relations hold information about generalisation operations or matching procedures to support, for instance, update propagation, quality and consistency checks, multi-resolution analysis functions, as well as zoom functionalities for web mapping and mobile applications (adaptive zooming). Update relations allow for history management, spatio-temporal analysis and can be a basis for a versioning, useful if parallel editing is carried out. If an incremental update should be carried out automatically, both inter-resolution and update relations are necessary.

Starting from one common relation class the three relation types can be derived and can be further specialised. The unification of all relations has the advantage that common operations of relations can be defined, for example as “give all features, which are characterised or connected with an element of a relation”. The unification further supports the standardised exchange of additional information besides features with their geometries and attributes for instance in a Service framework. Finally, a common model of relations supports the persistent storage of the elements of the relations.

There are some main differences between intra-resolution relations and inter-resolution respective update relations. First, of all intra-resolution relations characterise the states of features, while inter-resolution and update relations describe the changes of features. Secondly, the intra-resolution relations are modelled as n -ary relation (order of relationships between $1 \dots n$), while, in contrast, inter-resolution relations are binary, respectively unary, in case of removal or adding (e.g. matching) and update relations are also binary, respectively unary, in case of deletion or insertion.

For the several relation types some approaches for creation have been described and the differences of implementation discussed. Additionally, methods for visualisation are suggested and possible applications are explained. A final example showed the interrelationship during the generalisation process also considering the actualisation of the feature sets.

Further research will investigate relations between relations, for instance the inter-resolution or update relation between groups of features like an alignment modelled through a intra-resolution relation in more detail. Other interesting questions refer to the association of relations and cartographic constraints, for example preserving the density of a partition during generalisation. Finally, the model of relations hold potential for the extension or substitution of feature based models.

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